A COMPARISON OF THE DIFFERENT TYPES OF SWEETENING AGENTS AS PRESERVATIVES OF CONDENSED MILK

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN DAIRY HUSBANDRY IN THE GRADUATE COLLEGE OF THE UNIVERSITY OF ILLINOIS, 1944

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The main function of sugar added to sweetened condensed milk is to prevent microbial spoilage. In the past, the only sugar used in the manufacture of this product was the cane or beet sugar, sucrose. If any other sugar was added, it had to be declared on the label. However, in 1930 the use of corn sugar in food products in which sugar was a recognized element was legalized and could be used without declaration on the label.

Further modifications of this law were made on September 26, 1943, by the Food and Drug Administration in which the use of corn syrup and corn syrup solids were also permitted in the manufacture of sweetened condensed milk if they were declared on the label.

These modifications of the law concerning the use of the sweetening agents made from corn, and the scarcity of sucrose due to the war, have brought about an increase in the use of sweetening agents other than sucrose in the manufacture of sweetened condensed milk. It was deemed advisable, therefore, to study the relative preserving action of these sugars.

SCOPE AND PLAN OF THE STUDY

The following sweetening agents were compared as to their preserving action: sucrose, dextrose, invert syrup, Sweetose, confectioners' corn syrup and Frodex, which were added on a solids basis. Sweetose is the trade name for corn syrup having higher content of dextrose and maltose than the regular corn syrup. Frodex is the trade name for dehydrated confectioners' corn syrup. Invert syrup was prepared by the hydrolysis of sucrose.

The test microorganisms used were: Escherichia coli, Staphylococcus aureus, thermoduric micrococcus, yeast isolated from corn syrup and saccharomyces cerevisiae.

The study consisted of a series of separate experiments. In three of the experiments nutrient broth containing varying percentages of the sweetening agents was inoculated with the test microorganisms. In a fourth experiment, condensed skim milk containing the different sweetening agents was inoculated with the test microorganisms.

The inoculated broths and milks were stored for the most part at room temperature of about 75° F. At certain intervals of time, they were examined for visible spoilage, and if not spoiled, agar plate counts were determined.

The chemical composition of the sweetening agents is given in Table 1.

Sweetened condensed milks usually contain from 40 to 44 per cent sugar and 28 per cent milk solids, giving a total solids content of from 68 to 72 per cent. It has become a commercial practice to replace from one-fourth to one-half of the sucrose in the sweetened condensed milk when corn sweeteners are used. The effect of this replacement on the

Table 1
Chemical Composition of the Different Sweetening Agents

	Sweetening Agents					
	Sucrose	Cerelose	Invert Syrup	Sweetose	Frodex	Corn Syrup
% Sucrose	100	0	0	0	0	0
% Dextrose	0	92	50	30.6	22.0	17.6
% Maltose	0	0	0	27.9	20.8	16.6
% Levulose	0	0	50	0	0	0
% Higher Sugars	0	0	0	13.1	20.2	16.2
% Dextrines	0	0	0	9.9	37.0	29.6
% Water	....	..	..	18.2	....	19.7
% Ash	....	..	..	0.3	0.3	0.3
pH in 50% sol.	6.81	6.35	..	5.59	5.59	5.59

quality of the finished product has been studied by Ramsey, Tracy and Ruehe (1933). These workers concluded that in concentrated solutions dextrose was only slightly more efficient than sucrose as a preserving agent. They also presented data to show that at low concentrations, sucrose may exert more preserving power than dextrose, and at high concentrations, dextrose and sucrose may have approximately the same preserving power.

Edman (1939) concluded that, "The preserving power of Sweetose in condensed skim milk compares favorably with that of the dextrose and sucrose."

Numheimer and Fabian (1940), working with Staphylococci, found that dextrose exerted an inhibitive effect in concentrations of 30 to 40 per cent and a germicidal effect at 50 to 60 per cent. Whereas, for sucrose, 50 to 60 per cent was required for inhibition and 60 to 70 per cent for germicidal action. Erickson and Fabian (1942), using fructose, dextrose, sucrose, and lactose, studied the preserving action of the sugars on a number of bacteria and yeasts. The order of the preserving (inhibitive) action of the sugars on the bacteria was: fructose — dextrose — sucrose — lactose. From 15 to 25 per cent fructose was required to exert a preserving action compared with 25 to 32.5 per cent dextrose and 40 to 60 per cent sucrose. Lactose with a solubility of only 30 per cent did not have any preserving action. The percentage of sugar necessary to exert a preserving action was found to vary with the different bacteria, for example: Streptococcus lactis and Streptococcus liquefaciens required 25 per cent fructose while the thermophiles required only 17.5 per cent fructose. For dextrose, the preserving percentage was 30 to 32.5 for Streptococcus lactis and Streptococcus liquefaciens and for the thermophiles 27.5 per cent, whereas, for sucrose the former group had a preserving action at

60 per cent, while the latter group was inhibited at 40 per cent. The yeasts, these authors concluded, are more tolerant than bacteria to the sugars, since 45 to 60 per cent sugar was required to bring about a preserving action with yeasts, whereas, with bacteria the range was from 15 to 60 per cent to show comparable preserving action. The order of activity of the sugars for yeasts differed slightly from that of the bacteria in that fructose and dextrose exerted a preserving action at the same concentration of 45 to 55 per cent, while 60 per cent of sucrose was required to produce the same effect.

Erickson and Fabian (1942) further concluded that the order of the germicidal action of these sugars on bacteria was the same as the preserving (inhibitive) action with the exception that the Streptococcus lactis and Streptococcus liquefaciens, the sucrose (60 per cent) did not exert any germicidal action. Their data show that only fructose and dextrose exerted a germicidal action on all yeasts. These sugars required a concentration of 47.5 to kill all of the yeasts, while a concentration of 60 per cent sucrose was germicidal for only one yeast saccharomyces cerevisiae.

RESULTS OF THE STUDY

Experiment I

In experiments 1, 2, and 3 the sweetening agents used were: 1. invert syrup, 2. sucrose, 3. dextrose 50% + sucrose 50%, 4. Sweetose, 5. confectioners' corn syrup, and 6. Frodex. Since dextrose crystallized at 60 per cent concentration, it was mixed with sucrose at fifty-fifty ratio.

The concentrations of sweetening agent used in these experiments were 60, 62, 64, 66, and 68 per cent. Broths prepared with these concentrations were put in pint bottles and after inoculation were incubated at room temperature of about 75° F. The test microorganism used in Experiment I was a thermoduric micrococcus.

The sugar broth cultures were kept 95 days. Bacterial agar plate counts were made several times during this period, and the results as shown in Table 2 indicate that the invert syrup showed the most effective preserving action. Not only was there no increase in the number of the bacteria, but there was a complete destruction of them. The invert syrup was prepared by hydrolysis of sucrose by means of acid and heat. The acid was then neutralized so that this preserving action could not be attributed to low pH.

Dextrose-sucrose combination and Sweetose showed similar preserving action. At the end of 55 days, no living bacteria were found in the broths.

Confectioners' corn syrup at 60 per cent concentration did not inhibit the growth of the bacteria, but it did at the higher concentrations. No

Table 2

Preserving Action of Six Sweetening Agents Measured by a Thermoduric Micrococcus

	Days stored	Concentration of sugars				
		60%	62%	64%	66%	68%
		Numbers of organisms per ml.				
Invert syrup	0	1,130,000	1,010,000	690,000	850,000	880,000
	25	0	0	0	0	0
	55	0	0	0	0	0
	77	0	0	0	0	0
	95	0	0	0	0	0
Sucrose	0	1,140,000	840,000	880,000	780,000	850,000
	25	4,550,000	3,900,000	400,000	480,000	560,000
	55	7,900,000	2,900,000	1,740,000	330,000	172,000
	77	140,000	290,000	16,000	18,000	9,000
	95	42,000	86,000	3,000	0	0
Dextrose-sucrose 50-50	0	720,000	690,000	630,000	630,000	670,000
	25	7,000	2,000	2,000	1,000	1,000
	55	0	0	0	0	0
	77	0	0	0	0	0
	95	0	0	0	0	0
Sweetose	0	640,000	550,000	550,000	620,000	830,000
	25	10,000	3,000	3,000	0	0
	55	0	0	0	0	0
	77	0	0	0	0	0
	95	0	0	0	0	0
Confectioners' corn syrup	0	570,000	630,000	330,000	430,000	410,000
	25	3,260,000	10,000	0	0	0
	55	1,620,000	0	0	0	0
	77	1,450,000	0	0	0	0
	95	0	0	0	0	0
Frodex	0	440,000	780,000	400,000	390,000	540,000
	25	5,500,000	550,000	240,000	320,000	310,000
	55	2,500,000	720,000	170,000	210,000	242,000
	77	1,300,000	230,000	108,000	46,000	200
	95	1,520,000	51,000	24,000	17,000	7,150

living bacteria were found after 55 days of incubation in 62, 64, 66, and 68 concentrations.

In the 60 per cent concentration of Frodex the bacteria were able to multiply. In the other concentrations no multiplication took place. The number of bacteria gradually decreased, but a certain number of viable bacterial cells survived even after 95 days of storage.

The thermoduric bacteria were able to multiply in 60 and 62 and to

some extent in 64 per cent concentrations of sucrose. In 66 and 68 per cent concentrations, no multiplication took place.

The six sweetening agents may be arranged according to their preserving action on the thermoduric micrococcus in the following order, the first being the most effective: invert syrup, Sweetose, dextrose-sucrose, confectioners' corn syrup, followed by sucrose and Frodex, which appeared to have about equal preserving properties.

Experiment II

This experiment was performed in exactly the same manner as Experiment I, with the exception that the test organism was Staphylococcus aureus, a strain isolated from a food poisoning outbreak. The results are presented in Table 3.

Table 3

Preserving Action of Six Sweetening Agents Measured by Staphylococcus Aureus

	Days stored	Concentration of sugars				
		60%	62%	64%	66%	68%
		Numbers of organisms per ml.				
Invert syrup	0	830,000	1,280,000	1,210,000	1,100,000	1,470,000
	22	0	0	0	0	0
	37	0	0	0	0	0
	79	0	0	0	0	0
Sucrose	0	1,710,000	1,420,000	2,140,000	1,160,000	2,320,000
	22	1,600,000	1,200,000	630,000	810,000	420,000
	37	600,000	450,000	156,000	201,500	110,000
	79	40,000	25,000	970	0	230
Dextrose-sucrose 50-50	0	1,740,000	1,610,000	2,540,000	2,540,000	1,860,000
	22	0	0	0	0	0
	37	0	0	0	0	0
	79	0	0	0	0	0
Sweetose	0	1,260,000	1,310,000	1,430,000	1,430,000	1,230,000
	22	0	0	0	0	0
	37	0	0	0	0	0
	79	0	0	0	0	0
Confectioners' corn syrup	0	13,600,000	15,200,000	16,000,000	5,400,000	19,000,000
	22	1,230,000	860,000	640,000	450,000	600,000
	37	190,000	3,900	800	0	1,800
	79	18,900	0	0	0	0
Frodex	0	8,500,000	12,400,000	6,300,000	11,000,000	4,300,000
	22	690,000	670,000	480,000	330,000	410,000
	37	123,000	46,000	0	100	100
	79	0	0	0	0	0

The bacterial agar plate counts indicate that the Staphylococcus organism was unable to multiply in any of the concentrations of the sweetening agents. The bacteria were destroyed in all the concentrations of invert syrup, dextrose-sucrose, and Sweetose.

In Frodex, confectioners' syrup and in sucrose concentrations, the bacteria gradually decreased in number. In Frodex, they completely disappeared after 79 days of storage in all the concentrations. In confectioners' corn syrup, they disappeared except in 60 per cent concentration. In sucrose a few viable organisms were found in all the concentrations after 79 days of storage.

The six sweetening agents may be arranged according to their preserving action on Staphylococcus aureus as follows: invert syrup, dextrose-sucrose, and Sweetose had about the same preserving action, followed by Frodex, confectioners' corn syrup and sucrose.

Experiment III

This experiment was performed in the same manner as Experiment II, except that the test organism was a yeast isolated from corn syrup. The results of the experiment are given in Table 4.

This organism was unable to multiply in any of the concentrations of invert syrup. Prompt destruction of the organisms took place in the invert syrup concentrations used.

In Sweetose concentration of 60 per cent the organism was able to multiply and cause visible signs of fermentation after 58 days of storage. In the 62, 64, 66, and 68 per cent concentrations, there was a rapid decrease in the number of the organisms. By the 77th day, no viable organisms were present.

In the dextrose-sucrose concentrations of 60, 62, and 64 per cent, the organism was able to multiply and cause fermentation. The 66 and 68 per cent concentrations inhibited its growth.

In all the concentrations of sucrose, Frodex and confectioners' corn syrup, this organism was able to multiply and cause fermentation.

According to the results of this experiment, the sweetening agents may be arranged as to their preserving action as follows: invert syrup, Sweetose, dextrose-sucrose. The sucrose, Frodex and confectioners' corn syrup would not afford much preserving action with this particular yeast.

Experiment IV

In this experiment condensed skim milk was used instead of broth for testing the preserving action of the different sweetening agents.

In preparing the batches of condensed skim milk, the milk was heated at 170° F. for 30 minutes and then it was drawn into the vacuum pan. The sweetening agents were added in the form of a 65 per cent

Table 4
Preserving Action of Six Sweetening Agents Measured by a Certain Yeast

	Days stored	Concentration of sugars				
		60%	62%	64%	66%	68%
		Numbers of organisms per ml.				
Invert syrup	0	1,580,000	990,000	1,300,000	650,000	1,280,000
	15	0	0	0	0	0
	27	0	0	0	0	0
	58	0	0	0	0	0
	77	0	0	0	0	0
Sucrose 100%	0	1,220,000	1,360,000	1,030,000	1,220,000	1,100,000
	15	26,000,000**	26,650,000**	8,450,000**	110,000	140,000
	27	14,300,000**	35,750,000**	37,700,000**	7,800,000**	7,150,000**
	58	7,150,000**	2,600,000**	3,160,000**	2,120,000**	14,950,000**
	77	3,880,000**	5,200,000**	2,620,000**	1,810,000**	11,050,000**
Dextrose-sucrose 50-50	0	1,470,000	1,100,000	1,100,000	1,250,000	1,320,000
	15	64,000	500	100	0	0
	27	26,000,000**	1,480	160	0	0
	58	13,000,000**	5,000,000**	5,500,000**	0	0
	77	14,820,000**	19,500,000**	5,850,000**	0	0
Sweetose	0	1,500,000	1,320,000	1,520,000	1,540,000	1,450,000
	15	0	100	100	200	0
	27	34,450	0	0	0	0
	58	4,329,000**	20	10	0	0
	77	3,100,000**	0	0	0	0
Confectioners' corn syrup	0	1,190,000	1,760,000	1,460,000	1,670,000	1,240,000
	15	33,800,000**	35,100,000**	26,650,000**	8,450,000**	7,800,000
	27	10,400,000**	27,950,000**	11,700,000**	14,300,000**	7,800,000
	58	10,400,000**	8,450,000**	6,500,000**	7,800,000**	4,120,000**
	77	12,350,000**	7,150,000**	8,450,000**	13,650,000**	6,500,000**
Frodex	0	1,600,000	1,590,000	2,370,000	1,680,000*	2,360,000
	15	2,250,000**	3,780,000**	4,400,000**	1,500	7,220,000**
	27	11,700,000**	3,660,000**	5,200,000**	2,900	5,850,000**
	58	5,380,000**	1,900,000**	6,500,000**	17,800	1,200,000**
	77	2,120,000**	2,620,000**	190,000**	5,400	2,040,000**

* Recheck fermented in less than a week.
** Fermented.

water solution. This solution was heated to 195-200° F. for 5 minutes before being added to the skim milk in the vacuum pan.

The composition of the finished condensed skim milk was 69 per cent total solids of which 27 per cent was milk solids and 42 per cent sweetening agent solids.

The sweetening agents derived from corn cause condensed milk to

Table 5
Preserving Action of Six Sweetening Agents in Condensed Milk
Measured by Five Different Microorganisms

	Days stored	Micrococcus pikowskyi	E. Coli	Staph-aureus	Yeast from corn syrup	Sacch. cerevisiae
		Numbers of organisms per ml.				
Invert syrup	0	910,000	4,820,000	820,000	390,000	120,000
sucrose	5	860,000	3,770,000	870,000	290,000	23,000
50-50	18	770,000	1,800,000	760,000	57,000	6,900
	27	580,000	1,950,000	490,000	32,000	3,600
	47	440,000	210,000	380,000	9,000	1,000
	56	710,000	106,000	280,000	2,000	200
	64	680,000	5,600	36,000	600	100
Sucrose	0	700,000	4,110,000	870,000	520,000	90,000
100%	5	760,000	2,600,000	920,000	264,000	10,000
	18	3,980,000	1,800,000	870,000	450,000	2,700
	27	950,000	1,260,000	1,060,000	152,000	700
	47	1,230,000	810,000	730,000	574,000*	100
	56	1,000,000	110,000	17,550,000	670,000*	0
	64	1,900,000	121,000	480,000	57,000*	100
Dextrose-	0	910,000	4,500,000	720,000	500,000	60,000
sucrose	5	760,000	3,880,000	1,170,000	210,000	9,000
50-50	18	690,000	2,800,000	620,000	110,000	3,400
	27	740,000	1,400,000	710,000	106,000	2,000
	47	430,000	320,000	430,000	69,000	400
	56	930,000	28,000	80,000	26,000	100
	64	44,000	9,000	13,000	22,000	100
Sweetose	0	800,000	4,800,000	660,000	320,000	120,000
sucrose	5	890,000	4,550,000	770,000	175,000	26,000
50-50	18	750,000	3,000,000	700,000	91,000	13,600
	27	480,000	2,000,000	990,000	229,000	7,300
	47	410,000	190,000	480,000	570,000	2,300
	56	346,000	11,000	650,000	81,000	500
	64	560,000	17,800	450,000	34,000	500
Confectioners'	0	860,000	3,600,000	610,000	420,000	70,000
corn syrup	5	1,310,000	2,015,000	750,000	1,270,000	10,000
sucrose	18	1,140,000	1,770,000	660,000	2,540,000	9,500
33.33-66.67	27	710,000	1,900,000	910,000	2,400,000*	4,400
	47	1,030,000	670,000	580,000	2,900,000*	900
	56	1,180,000	400,000	990,000	2,700,000*	100
	64	1,370,000	350,000	469,000	100,000*	0
Frodex	0	540,000	3,510,000	510,000	370,000	50,000
sucrose	5	1,370,000	2,900,000	810,000	470,000	26,000
33.33-66.67	18	1,390,000	1,990,000	770,000	594,000	8,000
	27	870,000	2,000,000	770,000	2,600,000*	4,700
	47	940,000	690,000	810,000	690,000*	900
	56	1,180,000	580,000	900,000	17,550,000*	100
	64	1,200,000	300,000	6,500,000	1,500,000*	0

* Fermented.

turn dark and cause excessive thickening of the body. To reduce this thickening tendency, dextrose and Sweetose were mixed with sucrose on a 50% basis. The confectioners' syrup and Frodex caused even more thickening so were reduced to 33.33% sugar solids to 66.67% of sucrose.

After the sweetened condensed milk was inoculated, it was put in tin cans which were then sealed hermetically and stored at room temperature of about 75° F. for 64 days.

The inoculum was prepared from the microbial growth of 24-hour agar slants.

The inoculated cans of the condensed milk were examined seven times during the storage period for the presence and number of the viable microorganisms using agar plate method for this purpose.

In inoculating the thick sweetened condensed milk, it was practically impossible to distribute the inoculum uniformly throughout the body of the milk. This may partly account for the variable bacterial counts.

The condensed milk samples inoculated with the yeast isolated from corn syrup and sweetened with Frodex plus sucrose and those sweetened with confectioners' syrup plus sucrose spoiled in 27 days of storage. Those sweetened with sucrose spoiled in 47 days of storage.

All the other milks showed no visible signs of spoilage or changes of odor during the 64 days of storage.

The test organisms remained viable in varying numbers at the end of 64 days of storage. Some increase in numbers occurred in the milk inoculated with the thermoduric micrococcus in the milks sweetened with sucrose, Frodex plus sucrose and confectioners' corn syrup plus sucrose. In most other cases a gradual decrease in the viable microorganisms took place during the storage period.

The results of this experiment as shown in Table 5 indicate that the combinations of invert syrup and sucrose, Sweetose-sucrose, and dextrose-sucrose have about the same preserving action. Next would be sucrose, and then the Frodex-sucrose and confectioners' corn syrup-sucrose combinations, which exhibited about equal preserving action.

CONCLUSIONS

In general, sweetening agents high in monosaccharide content such as invert syrup, Sweetose, and dextrose are more efficient preserving agents than those low in monosaccharide content such as Frodex or confectioners' corn syrup or a disaccharide such as sucrose.

As the concentration of the sweetening agent is increased, its preserving action is also increased.

Sweetose is a more efficient preserving agent than either Frodex

or corn syrup. Its greater preserving power is probably due to its higher total sugar and monosaccharide content.

The preserving action of any of the sweetening agents used varies with the organism concerned.

Sweetened condensed skim milk containing 28 per cent milk solids and 42 per cent sugar, 50 per cent of which is sucrose and 50 per cent of either invert syrup, Sweetose or dextrose, can be more safely stored at room temperature without danger of spoilage by most bacteria or yeast than can those containing all sucrose.

Until more is known about the nature and structure of cell plasma membranes and the mechanisms by which substances in solution pass through them, it is not possible to state how sweetening agents exert a preserving action on microorganisms.

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VITA

The author was born on February 7, 1907, at Salt Lake City, Utah. He received his elementary education in the Salt Lake City public school system and his high school education at the Latter-day Saints High School, Salt Lake City, Utah. From 1926 to 1929 he resided in Germany as a missionary for the Church of Jesus Christ of Latter-day Saints.

From 1930 to 1932 he attended the University of Utah with a major in Business Administration. From 1935 to 1940 he attended the Utah State Agricultural College, receiving a Bachelor of Science degree in 1938 and a Master of Science degree in 1941 with a major in Dairy Manufactures. He held the position of assistant in the Dairy Husbandry Department of Utah State Agricultural College from October, 1938, until June, 1939, and the position of foreman of the College Creamery from August, 1939, until August, 1940.

He entered the Graduate School of the University of Illinois in the fall of 1940. He held the position of assistant in the Dairy Husbandry Department of the University of Illinois from September, 1940, until September, 1943, and the position of instructor from September, 1943, until June, 1944.

He is a member of Phi Kappa Phi, Sigma Xi, Gamma Sigma Delta, and Alpha Zeta.